The United States has ratified this STANAG and it is approved for use. Actual promulgation by NATO is expected within one year. At that time, this document will be replaced by the promulgated version. Any U.S. comments or reservations are included in the following letter.

Enclosure to
AC/310-D/192

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ELECTRO-EXPLOSIVE DEVICES ASSESSMENT AND TEST METHODS FOR CHARACTERIZATION

GUIDELINES FOR STANAG 4560

AOP-43

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NORTH ATLANTIC TREATY ORGANIZATION

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NATION	SPECIFICATION RESERVATIONS

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RECORD OF CHANGES

Change Date	Date Entered	Effective Date	By Whom Entered

ELECTRO-EXPLOSIVE DEVICES ASSESSMENT AND TEST METHODS FOR CHARACTERIZATION - GUIDELINES FOR STANAG 4560

AIM

1. The aim of this AOP is to guide engineers in the methods of characterization of Electro-Explosive Devices (EED) given in STANAG 4560.

INTRODUCTION

2. Comments listed follow the order in which they appear in STANAG 4560. Where given, the paragraph numbers shown in brackets indicate the relevant paragraph in STANAG 4560.

GUIDANCE ON STANAG 4560 EDITION 1

RELATED DOCUMENTS

3. The list is not exhaustive and test engineers should be aware that other relevant STANAGs may be in the course of development.

DEFINITIONS

4. It is emphasised that STANAG 4560 is for Characterization not Qualification and attention is drawn to these definitions at Para 3 of the STANAG. Definitions of terms specific to STANAG 4560 are to be found in the main body of the STANAG and AOP 38.

GENERAL

5. An EED is a one shot explosive or pyrotechnic device used as the initiating element in an explosive or mechanical train and which is activated by the application of electrical energy. For the purposes of this agreement the term includes, but is not limited to fuzeheads, caps, detonators igniters and initiators. There are a number of typical EED including Bridge-wire (BW), Film Bridge (FB), Conducting Composition (CC), Semi-conductor Bridge (SCB), Exploding Bridge-wire (EBW) and Exploding Foil Initiators (EFI)

6. EED are used widely within military systems to perform a variety of tasks, such as the initiating component in explosive trains, as gas generators, in heat or mechanical energy sources and to perform munition/system functions.

7. Assessment and characterization of the EED is required in support of National Authorities tasked to provide an impartial appraisal of the safety and suitability for service of weapons and those parts of weapon systems, stores and other devices in which EED are used.

8. This characterization is generic to the EED and the resulting data can be used to assess the electrical safety and to give a degree of confidence that when installed in a system the EED will meet the system environmental technical requirements. It is emphasised that characterisation is not Qualification but only the data to assist in the overall Qualification assessment. This needs to cover design and manufacture, including explosive content, initiation and output over a variety of general conditions of use.

9. EED can form a component part of a munition system or subsystem having no separate existence, save during manufacture, refurbishment or disposal, in the munition life cycle. Alternatively they may be fitted into a munition system late in the deployment phase such as when used for demolition purposes. In the latter case, the EED will usually experience a more severe overall environment than those that are installed within munitions.

10. Where the EED cannot be characterized in isolation the smallest testable item containing one of the above components shall be used with the approval of the National Safety Approving Authority (NSAA) or appropriate national authority. When characterizing an EED as the smallest testable component, the inherent safety features must be agreed by the NSAA before the data will be accepted.

ANNEX A

11. Annex A provides addresses of the National POC, where guidance may be sought on where characterization data, when formally requested, is possibly held.

ANNEX B

12. EED are one shot devices used as initiating elements in explosive or mechanical chains, which are actuated solely by the application of electrical energy. An explosive reaction process occurs in an EED when the temperature of a small amount of explosive is raised beyond its ignition temperature due to the heat, generated by the input of electrical energy or by detonation when struck by a flyer released, due to that increase in temperature.

13. The electrical input needed to initiate the EED can be obtained from sources installed within the system (weapon/store) or from external sources in, say a demolition firing unit or a launch platform connected to the weapon/store through an umbilical cable.

14. The output from an EED lags the input by a time dependent upon the physical and chemical properties of the active components of the device. This is often called the reaction time, which is the time taken from application of the stimulus to the measurable output.

15. When electrical power is dissipated in a resistive wire the temperature distribution in the wire and surrounding explosive will depend on a number of electrical and thermal parameters which are difficult to quantify. These parameters control the rate at which the BW responds thermally to the applied power. On the application of a step function of power the BW temperature approaches an equilibrium value almost exponentially. This rise may be characterised by a parameter called the thermal time constant (τ or T_C), which is related to the thermal response time of the EED as opposed to the reaction (or functioning) time.

$$T_{(t)}=T_{(max)}(1-e^{(-t/\tau)})$$

Where:

$T_{(t)}$ = Temperature rise after time t
(= [temperature at time t] – [initial temperature]

$T_{(max)}$ = At equilibrium, when dT/dt tends to zero, heat lost will equal heat input and the temperature will reach its maximum value.

τ = Thermal Time Constant.

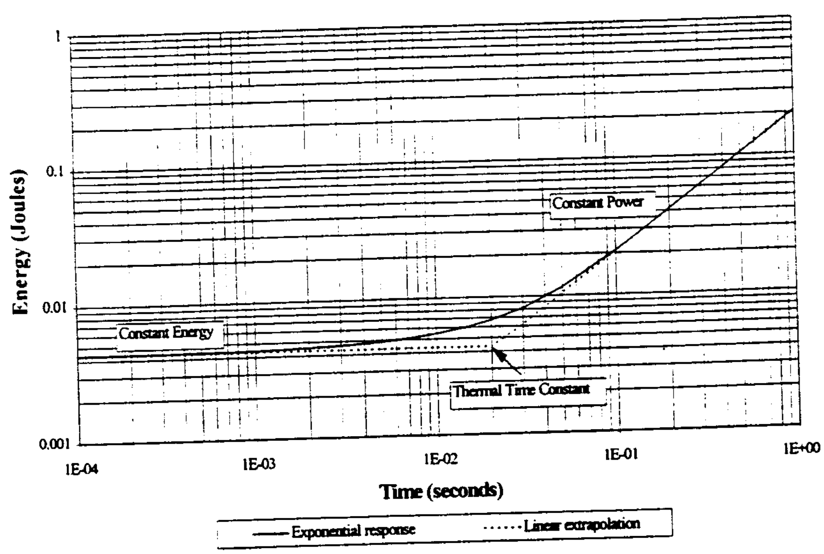
16. For a wire heated electrically, its final maximum temperature rise at any point will be proportional to the input power level, so after a time t the temperature rise will be:

$$T_{(t)}=kP(1-e^{(-t/\tau)})$$

where **k** is the constant of proportionality

17. When power is dissipated for a time significantly longer than τ, the power required to raise the BW to an initiation temperature is independent of pulse width. When power is dissipated for a time shorter than τ as a result of reducing the pulse width, heating becomes increasingly adiabatic, that is electrical energy is employed more effectively as heat losses reduce. At a pulse width of approximately 0.1 τ a constant energy region is approached where the energy required for ignition approaches a constant value as pulse width (with increasing power levels) approaches zero. This is illustrated in the graph below:

Typical EED Characteristic



18. No-Fire Threshold (NFT) Sensitivities. It is impractical to attempt to define uniquely the stimulus level at which none of a particular batch of EED will fire. The threshold sensitivity of the EED is usually derived from statistical measurements, an assumption being made that the probability distribution of sensitivity obeys a normal law, when the logarithm of the applied stimulus is taken as the independent variable. The NFT is defined in terms of the level at which 0.1% or 1.0% of the devices will fire. Due allowance is made for sampling errors by using the single-sided lower 95% confidence level for the 0.1% or 1.0% probability of firing. (The relevant NSAA or appropriate national authority should be consulted in order to confirm which percentage shall apply.)

19. No-Fire Threshold Power/Current. The threshold power/current of an EED is defined as the power/current required to produce a 0.1% or 1.0% probability of fire at the 95% single-sided lower confidence level when applied to the EED for a time which is significantly greater than the thermal time constant of the device, (eg >10 τ).

20. No-Fire Threshold Energy. The threshold energy is defined as the energy which would produce a 0.1% probability of fire at the 95% single-sided lower confidence level if applied to the EED for a time which is significantly less than the thermal time constant of the device, (eg <0.1 τ).

21. There is a general trend towards achieving power thresholds in excess of 1 W although some EED in present use have power thresholds quoted below 10 mW. In a particular device, low power and energy sensitivity are not always linked, for example some CC and FB EED have power thresholds in excess of 1 W yet energy threshold less than 50 µJ (due to the T_τ). This feature has definite advantages in particular designs for system applications where energy sensitivity is a design requirement, but is to be avoided where rf or transient susceptibility is likely to be a relevant factor.

22. Power/current thresholds are used to assess the behaviour of EED in Continuous Wave (CW) rf environments where EED time constants are of little consequence. However, in an rf pulsed environment, susceptibility levels change significantly depending on radar pulse parameters and EED time constants can be of major importance. Peak powers in a pulsed radar environment could be more than 1000 times the equivalent mean power and a knowledge of the response to the short duration peaks is essential. This is also applicable to lightning, Electromagnetic Pulse (EMP) and Electrostatic Discharge (ESD).

23. The majority of experience to date on EED sensitivity behaviour is related to that described in the previous section, where energy and power are the controlling parameters. Detailed analytical studies have been carried out to determine the nature of the bridge heating phenomena in conventional types of BW and FB EED. This work has been extended to cover electrical heating effects in the explosive components of both CC and metal cased BW devices. Over the frequency range dc to over 10 GHz CW, it has been demonstrated by the use of experimentation and theoretical modelling that, for a normal mode of initiation, sensitivity is a decreasing function of frequency.

24. Characterization of the EED is required in support of National Authorities tasked to provide an impartial appraisal of the safety and suitability for service of weapon and those parts of weapon systems and stores in which EED are used. Annex B identifies the method and EED characterization testing needed to provide the foundation data used in this appraisal. It is emphasised that characterisation is not Qualification or full appraisal but only the data to assist in the overall Qualification assessment The tests identified in this Annex are not exhaustive and should be considered as a minimum requirement in the characterization of an EED.

a. Electrical:

(1) EED resistance. (Either spread or geometric mean of the sample tested)

(2) All-fire and No-fire Thresholds. (Power or Current and Energy) These thresholds are obtained from statistical test data and are usually given at a specified confidence level. Nevertheless, in order to allow the predicted input level corresponding to any probability (or vice versa) to be determined by the individual nation, all details of the tests should be provided. These details include test method, number of samples and shot results with, as a minimum, the mean value and the standard deviation.

(3) Malfunction Threshold. For EFI the Malfunction Threshold should also be determine.

(4) Thermal Time Constant.

(5) Electro-static Discharge (25 kV).

b. Environmental. Often the range and effect of environments to which the EED is likely to be exposed will be determined by assessment of its proposed life cycle. Where a general understanding of the reliability of an EED is required the national documents give guidance to the levels of test severity that should be applied. The effect of these environments upon a particular EED may be assessed by analogy to previous data on the safety and suitability of another EED of a similar design. Generally, however, tests are required and typical information that should be provided is as follows:

(1) Thermal shock

(2) Humidity

(3) Leakage

(4) 1.5 m Drop

(5) Electric Cook-off

(6) Vibration

(7) Shock

25. In assessing the suitability of an EED after characterization, the following will need to be addressed:

a. The EED should provide the desired response when supplied with the specified electrical input.

b. The EED should not function inadvertently under any natural or induced conditions likely to be encountered throughout its Manufacture to Target or Disposal Sequence (MTDS).

c. The output from the EED should not be degraded unacceptably by internal change caused by exposure to the external environments it is likely to experience over its intended life cycle.

d. The EED should be reliable and safe to assemble and handle.

26. The method by which the characteristics of an EED will be assessed as safe and suitable for use will involve:

a. A design assessment including a hazard assessment.

b. The formal qualification of the explosives used in the EED.

c. Tests to ensure the compatibility of explosives and materials used.

d. Environmental tests.

e. Electrical characterization of the EED.

f. Performance tests at temperature extremes.

27. Design Assessment. The design assessment of an EED will be based upon documented evidence which will assist verification against the needs given in Paragraph 25.

a. The following information will assist in the assessment process:

(1) Production standard drawings.

(2) Specifications of the materials used including physical and chemical properties likely to be relevant; such as strength, stability, compatibility etc.

(3) Manufacturing processes.

(4) Quality plan.

b. Hazard Assessment. A hazard assessment should be conducted for the EED as an independent item. Design shortcomings and random failure of components in the EED should be considered. The measures taken to reduce the risk of inadvertent initiation should be stated, where appropriate.

c. Environmental Assessment. The range and effect of environments to which the EED is likely to be exposed needs to be determined by assessment of its proposed life cycle. Generally tests are required (see para 30).

d. Two modes of EED application can be considered in the assessment:

(1) Where the EED is installed early in the life of a munition

(2) Where the EED exists as an independent item for most of its life, such as when fitted to a demolition charge prior to firing.

28. Qualification of Explosives for use within an EED. Qualification, as opposed to Characterization, is the assessment of an explosive by the National Safety Approving Authority (NSAA) or other appropriate authority to determine if it possesses properties which make it safe and suitable for consideration for use in the intended role. It is a risk reduction exercise and is an intermediate stage leading to Type Qualification. Explosive materials proposed for military use should be assessed in accordance with the principles and methodology given in STANAG 4170 (AOP-7).

29. Compatibility. Within the EED, explosive compounds are in intimate contact with metals and non-metallic materials and the compounds need to be compatible with them. Compatibility can be assessed either from a programme of testing (see STANAG 4147) or by read-across from previous tests.

30. Environmental Tests. A sequential environmental tests programme should be designed to cover the relevant tests listed in Annex B. Where appropriate these test should be in accordance with STANAG 4370 or national standards and should reflect the MTDS for the EED as a separate item.

31. Electrical Characterization (Firing Properties Test). It is important for safety and suitability for service reasons to know the level of energy or power at which an EED will be initiated or to be able to calculate the probability of firing if the EED is exposed to any input level. From the firing properties test, 2 thresholds can be derived. These are:

a. The no-fire threshold, (see Para 3.k. of STANAG 4560).

b. The all-fire threshold, (see Para 3.l. of STANAG 4560).

These thresholds are obtained from statistical test data and are usually given at a specified confidence level. Nevertheless, in order to allow the predicted input level corresponding to any probability (or vice versa) to be determined, all details of the tests should be provided as required by the NSAA or other appropriated authority. These details include test method, number of samples and shot results with, as a minimum, the mean value and the standard deviation. Note: Where the response of the EED is assumed to follow a normal or log-normal law, typical values used are: a no-fire probability of 0.1% (or 1% for France) and an all-fire probability of 99.9% (or 99% for France) both at a single sided confidence level of 95%.

32. Other tests. Other characterization tests to determine the susceptibility of the EED to external stimuli are required as shown in Annex B.

33. Performance Characteristics. The output will be determined by the type of explosive compositions used, their quantity, degree of confinement and temperature. The tests may need to cover a variety of applications to measure the amplitude and duration of the particular events but examples of attributes requiring characterization are shock, flash and the generation of gas.

ANNEX C

34. BW, FB, and CC have been characterised over the past 35 years using national test procedures. These procedures, though different, are normally considered adequate tests providing the NSAA or other appropriate authority has monitored them. At Annex C is listed national documentation which is widely accepted throughout NATO. Data obtained by carrying out these procedures should be maintained by the NSAA or other appropriated authority.

35. Where appropriate the national authority should be able to offer to other NATO users the data and results on some if not all the tests listed in Annex B.

ANNEX D

36. High voltage devices in which the wire or film bridge is designed to explode are operated by the discharge of energy from a secondary store such as a capacitor. Correct functioning is only obtained if the energy is delivered to the bridge as a tailored pulse, with a rapid rise time, to a current peak of kA magnitude. Although it is unlikely that such a pulse can be generated in any way other than by the design source, it is still necessary to establish the level of power/energy that will affect the subsequent functioning of the device.

37. Though investigation of the parameters of such devices is still under consideration, the present accepted technique to identify the required parameters is given in Annex D.

38. Resistance. (Annex D Para 5) A conventional multimeter measures resistance by passing a known current through the item under test (IUT) and measuring the voltage produced by this current. Measurements of resistance are subject to 3 sources of error, which are more significant when measuring lower values ($<1\Omega$). These are:

a. Resistance of test leads. If the measurement is made on the resistance range of a multimeter, the result will include the resistance of the test leads. A correction can be made for this resistance but there will be a loss of accuracy.

b. Contact Resistance of Test Probes. Connection of the measuring instrument to the IUT will introduce contact resistance at each end of both of the test leads. These resistances are random, variable and difficult to control. As they cannot be quantified, corrections for them cannot be made.

c. Thermo-electric Potentials. The test circuit is likely to include contact between dissimilar metals. If these contacts are at different temperatures, thermo-electric voltages will be generated. These may be large enough to cause significant errors, particularly if the measuring instrument is passing a current of 1 mA or less through the IUT.

39. Errors from the above sources can be minimised by correct use of a four terminal measuring instrument. This will have separate terminals for its current source and voltmeter. The current source drives the correct value of current through the IUT regardless of stray resistance in test leads or connections. The voltage terminals of the instrument must be connected separately to the IUT. The voltage reading will then not be affected by any reasonable value of resistance in the test leads or contacts. Errors from effects (a) and (b) are thus kept to a minimum. To reduce possible errors from source (c), higher values of test current should be used, e.g. 10 mA to 100 mA, so that the voltage produced across the IUT is large compared with any thermo-electric potentials (usually 10's of microvolts). To check whether there are still errors from this source, the connections of the voltage measuring probes to the IUT should be interchanged. If the positive and negative voltage readings are different, an average of the two magnitudes will give a more accurate result, e.g. if a 10 mA current source produces readings of $+190\ \mu V$ and $-210\ \mu V$ across the IUT, its resistance should be taken as $(190\ \mu V + 210\ \mu V)/(2 \times 10\ mA) = 20\ m\Omega$.

40. The resistance should be quoted as either the maximum and minimum range of the devices or the geometric mean of all devices measured during the test.

41. Firing Properties. (Annex D Para 6) Reporting the electrical parameters of a system provides guidance to the designer on the voltage required at the source to provide reliable detonation. This also gives the margin below the stated no-fire threshold at which the system can be considered armed.

a. EFI operate on specific pulse characteristics and therefore the firing unit shall use the same circuit components as those used in the intended munition's tactical firing unit (Fire Set). Due to the possible degradation of the firing pulse because of deterioration of the triggering device and/or firing capacitor, each Fire Set should be triggered no more than half its projected number of reliable firings. Normally this should not be more than 50 times.

b. When the Fire Set has been used at lower energy levels than its operational level, the fire set should be reset, with a full strength fire pulse, every 5 firings.

c. Statistical analysis of the firing properties data shall be used to predict the minimum All-Fire Threshold Voltage (AFTV) and the maximum No-Fire Threshold Voltage (NFTV) of the EFI/EBW using all 3 temperatures. If the initiator cannot be fired within the temperature chamber, the initiator and the circuitry shall be inserted into an insulating container and transferred to the firing location as soon as possible.

42. Malfunction Threshold. (Annex D Para 7). Unlike BW, FBW and CC devices, where the total AFT is not very different from the total NFT, an EFI has a more discernible transition between visible or measurable damage of the bridge and detonation of the pellet. The electrical pulse having a well-defined characteristic to produce a flyer with the correct velocity and size to cause detonation, is unlikely to be generated by external influences. However, sufficient electrical energy could be generated within the system to cause damage to the bridge, which may or may not cause film shear to occur, which does not result in initiation of the explosive. Although such a situation would not lead to inadvertent initiation, the system may be incapable of correct operation, when a valid firing pulse is received. Therefore it is more relevant to define a malfunction threshold (MFT).

a. The MFT is defined as the stimulus, (voltage current or power) when applied to the EED, that produces a 0.1% probability of damage at the 95% single-sided lower confidence level, such that the EED will not fire when subjected to the operational firing pulse from the tactical fireset.

b. This is the parameter which should be used during HERO/RADHAZ trials when assessing the susceptibility of a system containing an EFI.

c. The requirement given in Annex D will require a minimum sample of 30 where the manufacturer has provided an acceptable malfunction threshold. Where this is not the case more will be required as advised by the NSAA or appropriate national authority.

43. Where a worse case assessment is considered acceptable, as no explosive is used during the characterization, the MFT is determined by the minimum current that produces visible damage (physical) or measurable change in electrical (Resistance) parameters.

44. Bridge Opening Current. The electrical pulse required to produce a flyer to cause detonation must have a well defined characteristic. There is a possibility that lesser values could cause heating effects which may migrate to the explosive. The bridge opening test, which will be carried out if the NSAA considers it appropriate, is to determine whether there is any burning , charring, scorching or melting of the explosive. This is known as the Bridge Opening Current. This level will be higher than that determined by the MFT and will give a degree of confidence on the safety margin when the device is subjected a continuous induced current.

45. Static Discharge (25 kV). (Annex D Para 8). Through a normal logistic cycle, weapons may undergo various phases of handling, such as packing, unpacking, wrapping in protective plastics or other coverings, assembling, transporting, loading and unloading etc. These processes may result in the development of an electrostatic charge on the handlers, transfer equipment, shipping container, munition weapon system or any ungrounded object. This charge if transferred or discharged through the EED, munition or weapon system, may be sufficient to produce a dud or even exceed the threshold level for firing the EED. This may result in a catastrophic ignition of the propellant or explosive, depending on the design of the system.

a. STANAG 4235 defines the maximum human electrostatic environment likely to be encountered by EED, and munition weapon systems containing EED, during handling, transportation and deployment.

b. The assessment of the electro-static discharge (ESD) susceptibility of the EED, munition and /or associated system should be conducted in accordance with STANAG 4239 and its test procedures (AOP-24).

46. Electrical cook-off. This test is used to determine the sensitivity of a test sample to accidental exposure to power sources up to 500V, for example form a ground loop. The requirement in STANAG 4187 is that the electrical initiator:

a. Shall not be capable of being detonated by any electrical potential of less than 500 V applied directly to the initiator.

b. Shall not be capable of being initiated by an electrical potential of less than 500 V when applied to any accessible part of the fuzing system during and after installation into the munition or any munition subsystem.

47. Environmental testing. All remaining environmental tests should be carried out in accordance with STANAGs 4370 and 4157. Specifically the vibration test regime chosen should replicate that environment encountered by stores designed for external captive flight.